Perception, 1992, volume 21, pages 359-363

The effect of defocussing the image on the perception of the temporal order of flashing lights

Saul M Luria, James S Newacheck
Naval Submarine Medical Research Laboratory, Naval Submarine Base New London, Groton, CT, USA
Received 26 October 1990, in revised form 14 September 1991

Abstract. The temporal interval between flashing lights that is required to perceive nonsimultaneity decreases as the refractive error increases from 0 to +2 diopters. The interval then remains constant with further increases to 3 and 4 diopters. The results are discussed in terms of the relative increase of transient to sustained visual channels and of the increase in apparent movement.

1 Introduction
In a number of studies the amount of time that must elapse between the presentation of two spatially disparate stimuli for the perception of temporal order or of nonsimultaneity have been measured (Efron 1963; Hirsch and Sherrick 1961; Lichtenstein 1961; Mayzner and Agresti 1978; Parks 1968; Robinson 1967; Rutschmann 1966, 1973; Sweet 1953; Westheimer and McKee 1977). From these studies it has been concluded that the perception of temporal order requires a temporal interval of from 3 to 50 ms, depending on the experimental conditions and criteria. It is clear that a number of variables have an effect on the value.

One of the variables which has apparently not been studied is the effect of defocussing the visual display. One might expect this to degrade visual performance as it does, for example, with foveal or Snellen visual acuity. But this is not always the case. Although refractive error quickly degrades Snellen acuity, it has little effect on peripheral acuity (Millodot et al 1975) and even less effect on grating acuity (Thorn and Schwartz 1990). Refractive error affects size constancy but not shape constancy (Leibowitz et al 1978). In some cases, defocussing of the retinal image actually results in an improvement in visual performance; Harmon (1973) showed that recognition of block faces is improved, and Gordon and Field (1978) reported better performance on pseudoisochromatic plates.

Of more relevance to the question of the perception of temporal order are the findings of Di Lollo and Woods (1981): defocussing the image decreases the duration of visual persistence. This suggests that the ability to perceive that two stimuli are not simultaneous may be enhanced in this way.

2 Method
2.1 *Subjects*
Ten staff members of the laboratory volunteered to serve as subjects. They ranged in age from 23 to 62 years (mean, 40.8 ± 10.7 years). All but one were corrected to 20/20 visual acuity; the tenth subject could only be corrected to 20/30, but his results were the same as the others and were therefore included. Only two of the subjects had any knowledge about the purpose of the experiment.

2.2 *Apparatus*
The observers viewed two lights flashing every 2 s. The flashing lights were produced by two sets of two concentric cylinders. The two inner cylinders were yoked and made to rotate in opposite directions (figure 1). The left cylinder rotated at a given

speed, x, and presented two flashes for each rotation; the right cylinder rotated at twice that speed, $2x$, and presented only one flash per rotation. This arrangement allowed the temporal interval between the right and left flashes to be varied by changing the aspect of the yoked outer cylinders, an adjustment that was not perceptible to the subjects. When the apertures in the outer cylinders were directly in the line of sight, the two flashes were simultaneous. When the outer cylinder apertures were rotated to the left of the direct line of sight, the left light flashed first; when the outer cylinders were rotated to the right of the direct line of sight, the right light flashed first. The more the outer cylinders were rotated, the longer the temporal interval between the pair of flashes. At the viewing distance of 20 ft (6.1 m), the spatial separation of the lights was 0.78 deg, and each light subtended 0.01 deg visual angle. The luminance was 230 cd m^{-2}, and the flash duration was 50 ms. The opening of the right cylinder was larger than that of the left cylinder to compensate for its faster speed of rotation. The experiments were carried out in a dimly illuminated room in which the subjects could just see large objects; a gray wall beside the apparatus, for example, was illuminated to 0.002 cd m^{-2}. This ambient illumination tended to preclude an autokinetic illusion. The cylinders themselves were screened from view; the subjects could not see them being set.

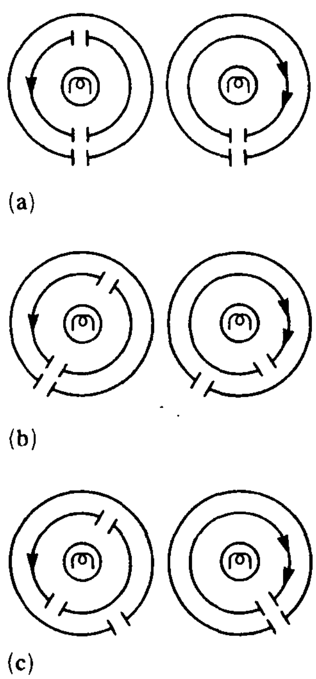

Figure 1. Diagram of the apparatus. The two inner cylinders are yoked. That on the left has two apertures and rotates counterclockwise at a given speed to produce one flash every 2 s. The inner cylinder on the right has one aperture and rotates clockwise at twice that speed to produce one flash every 2 s. The outer cylinders are also yoked, and when they are set at different positions, the temporal interval between the two flashes varies. When they are on center (a), the lights flash simultaneously; when they are rotated to the left of the direct line of sight (b), the left light will appear first, and the right light will appear later. When they are rotated to the right of the direct line of sight (c), the right light will appear first.

2.3 *Procedure*

The observers were adapted to the ambient illumination for 2 min. They wore a set of trial frames containing lenses to correct their refractive errors, combined with lenses of 0, +1, +2, +3, or +4 diopters (D) to produce the defocus blur.

They viewed the two lights which were either flashing simultaneously or with a given temporal interval. On half the nonsimultaneous presentations, the left light appeared first; on the other half of these presentations, the right light appeared first. The subjects reported whether the lights were flashing simultaneously, or whether the left or right light was flashing first. The magnitude of the temporal interval between the flashes needed for a correct judgment of temporal order (left light first versus right light first) was measured. All thresholds were obtained with the method of constant stimuli. A series of about six or eight temporal intervals, varying in 5 ms steps, was first chosen both for right-first and for left-first conditions by using the method of limits. These encompassed the range from simultaneity to an interval which allowed the subject to identify correctly the temporal order at least 80% of the time. A given temporal interval was set, and the flashing lights were exposed until the observer made a judgment. The lights were then occluded while a new temporal interval was set at random, and so on. Each setting was presented at least four times. The subjects were not told whether their responses were correct or not. A probit analysis was carried out for both right-first and left-first trials, and the mean of the two intervals at which the correct temporal order was identified 50% of the time was taken as the threshold. The order of presentation of the five defocussed conditions was counterbalanced across subjects.

3 Results

Figure 2 shows the mean threshold temporal interval for each refractive error. As refractive error increased, the mean temporal interval at threshold decreased significantly according to the Friedman Analysis of Variance by Ranks ($\chi_4^2 = 26.24$, $p < 0.0001$). It is obvious, however, that the significant decrease occurred between refractive errors of zero and +2 D. As refractive error was further increased to +4 D, there was no further decrease in the temporal interval. The standard deviations of each of the ten observers' thresholds were averaged at each blur level. There were no systematic changes in these mean values as the blur level varied.

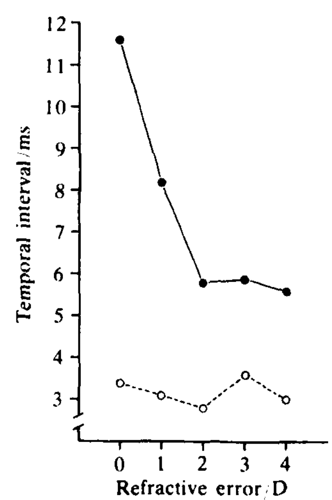

Figure 2. Temporal interval required to perceive the order of flashing as a function of refractive error (solid line). The dashed line shows the mean of the standard deviations for each subject at each blur level.

4 Discussion

These results are an interesting perceptual phenomenon and one of some practical importance. Indeed, the apparatus is a model of a proposed navigation beacon. Blurring the visual image significantly improves the ability to perceive that two light flashes are not simultaneous and to judge their temporal order.

The visual system must separate the time of the activity of one flash from that of the other in order to perceive nonsimultaneity. Blurring the visual image produces two major changes: it increases the apparent size of the stimulus, and it shifts energy from the higher to the lower spatial frequencies. The visual channels sensitive to the low spatial frequencies have shorter response latencies and higher temporal frequencies (Breitmeyer 1975; Fukuda 1971). That is, the mechanisms sensitive to low spatial frequencies have a greater temporal sensitivity than those sensitive to high spatial frequencies. Defocussing the image should thus improve the ability to distinguish nonsimultaneity by exploiting the temporal response characteristics of the transient-like visual mechanisms.

Blurring may also have altered the spatial characteristics of the stimuli to favor those visual mechanisms sensitive to movement. Post and Leibowitz (1981) found that correcting peripheral refractive errors increases movement sensitivity for displays of short duration. Several investigators have found that sensitivity to the movement of suprathreshold gratings is greatest when the spatial frequency of the target is around 4 cycles deg^{-1} and decreases as the spatial frequency increases (Campbell and Maffei 1981; Thompson 1983; Watanabe et al 1968).

Finally, the blurring of the image also resulted in another phenomenon; the subjects reported that there was now a marked perception of apparent motion when the two stimuli were not simultaneous. They no longer needed to rely on a difficult temporal judgment but could now respond on the basis of a salient perception of direction of movement. The enlargement of the images of the stimuli as a result of the blurring reduced the distance between the stimuli; according to Korte's laws (Anstis 1986), this reduces the optimal temporal interval for apparent motion. Apparent movement is seen through a wide range of temporal intervals, but the temporal range constricts as the spatial separation is increased, and the probability of seeing movement decreases (Kolers 1972). Indeed, von Grunau (1978) has shown that the likelihood of seeing apparent movement is increased when the light stimuli are defocussed.

The question arises, why did performance improve markedly with blurring of +2D but only slightly with increased blurring of +3 and +4D? Braddick's (1974) results appear to provide an explanation. He found that random-dot patterns separated by less than 15 min arc gave good apparent movement with very short temporal intervals. Longer temporal intervals require larger spatial separations. The +2D lens transformed the pinpoints of light into large disks which looked like disks of random dots which almost touched; increased blurring made them overlap more and more, but they did not look much different. Apparently, the +2D lens reduced the spatial interval almost to its optimal size, and further blurring had little effect.

Thus, it is likely that several factors may play a part in the improvement in the ability to perceive temporal order that results from the defocussing of the stimulus

Acknowledgments. This research was carried out under a contract from the US Coast Guard Research and Development Center, contract MIPR Z51100-9-0002, entitled "Evaluation of navigation range lights".

The views are those of the authors and do not reflect the official policy of the Department of the Navy or the Department of Defense.

References

Anstis S, 1986 "Motion perception in the frontal plane" in *Handbook of Perception and Human Performance* volume 1 *Sensory Processes and Perception* Eds K R Boff, L Kaufman, J P Thomas (New York: John Wilev) pp 16-1 - 16-27

Braddick O, 1974 "A short-range process in apparent motion" *Vision Research* **14** 519 - 527

Breitmeyer B, 1975 "Simple reaction time as a measure of the temporal response properties of transient and sustained channels" *Vision Research* **15** 1411 - 1412

Campbell F W, Maffei L, 1981 "The influence of spatial frequency and contrast on the perception of moving patterns" *Vision Research* **21** 713 - 721

Di Lollo V, Woods E, 1981 "Duration of visible persistence in relation to range of spatial frequencies" *Journal of Experimental Psychology: Human Perception and Performance* **7** 754 - 769

Efron R, 1963 "The effect of handedness on the perception of simultaneity and temporal order" *Brain* **86** 261 - 284

Fukuda Y, 1971 "Receptive field organization of cat optic nerve fibers with special reference to conduction velocity" *Vision Research* **11** 209 - 226

Gordon I E, Field D, 1978 "A possible explanation as to why the newly sighted commonly perform well on pseudoisochromatic colour vision tests" *Perception* **7** 119 - 122

Grunau M W von, 1978 "Interaction between sustained and transient channels: form inhibits motion in the human visual system" *Vision Research* **18** 197 - 201

Harmon L D, 1973 "The recognition of faces" *Scientific American* **229** (November) 70 - 82

Hirsch I J, Sherrick C E Jr, 1961 "Perceived order in different sense modalities" *Journal of Experimental Psychology* **62** 423 - 432

Kolers P A, 1972 *Aspects of Motion Perception* (New York: Pergamon Press)

Leibowitz H W, Wilcox S B, Post R B, 1978 "The effect of refractive error on size constancy and shape constancy" *Perception* **7** 557 - 562

Lichtenstein M, 1961 "Phenomenal simultaneity with irregular timing of components of the visual stimulus" *Perceptual Motor Skills* **12** 47 - 60

Mayzner M S, Agresti W W, 1978 "On an illusion of visual temporal order" *Bulletin Psychonomic Society* **12** 451 - 452

Millodot M, Johnson C A, Lamont A, Leibowitz H W, 1975 "Effect of dioptrics on peripheral visual acuity" *Vision Research* **15** 1357 - 1362

Parks T E, 1968 "The spatial separation of two light-flashes and their perceived separation in time" *American Journal Psychology* **81** 92 - 98

Post R B, Leibowitz H W, 1981 "The effect of refractive error on central and peripheral motion sensitivity at various exposure durations" *Perception & Psychophysics* **29** 91 - 94

Robinson D N, 1967 "Visual discrimination of temporal order" *Science* **156** 1263 - 1264

Rutschmann R, 1966 "Perception of temporal order and relative visual latency" *Science* **152** 1099 - 1101

Rutschmann R, 1973 "Visual perception of temporal order" in *Attention and Performance* volume IV, Ed. S Kornblum (New York: Academic Press) pp 687 - 701

Sweet A L, 1953 "Temporal discrimination by the human eye" *American Journal Psychology* **66** 185 - 198

Thompson P, 1983 "Discrimination of moving gratings at and above detection threshold" *Vision Research* **23** 1533 - 1538

Thorn F, Schwartz F, 1990 "Effects of dioptric blur on Snellen and grating acuity" *Optometry and Visual Science* **67** 3 - 7

Watanabe A, Mori T, Nagita S, Hiwatashi K, 1968 "Spatial sine-wave responses of the human visual system" *Vision Research* **8** 1245 - 1263

Westheimer G, McKee S P, 1977 "Perception of temporal order in adjacent visual stimuli" *Vision Research* **17** 887 - 892